NASA Ames Research Center – Aeromechanics Office

Rotorcraft as Robots

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Vertical Flight Society
San Francisco Bay Area Chapter

Abstract

- This is not a discussion about autonomous helicopters
- This is instead a talk about rotorcraft that are robots
  - i.e. platforms that have some level of capability to transform their nature and/or manipulate their environments
- Further, it is a talk about how these robotic rotorcraft may also transport, coordinate, and/or work closely with a heterogeneous mix of other robots to accomplish their missions

Abstract Cont.

- This talk attempts to make the point that wholly new vehicle configurations – and nontraditional aerospace applications – can be engendered by making this rather subtle shift in the design paradigm.

- Over the past two decides, the speaker has been conceptually exploring this idea of rotorcraft as robots

Outline

- Objective of talk
- Three perspectives
- Specific examples from past work of “rotorcraft as robots”
  - Planetary science
  - Terrestrial field science & monitoring
  - Public service
  - Disaster relief and emergency response
  - Public transportation
- Systems analysis applied to autonomy
- Concluding remarks

Objective

- Hopefully this talk will provoke thoughts/ideas as to new application domains outside of the conventional aerospace sector

- To additionally inspire innovation, particularly for a new generation of students and graduates, from this fusion of robotics, intelligent systems, and aerial vehicles

Discussion from Three Perspectives

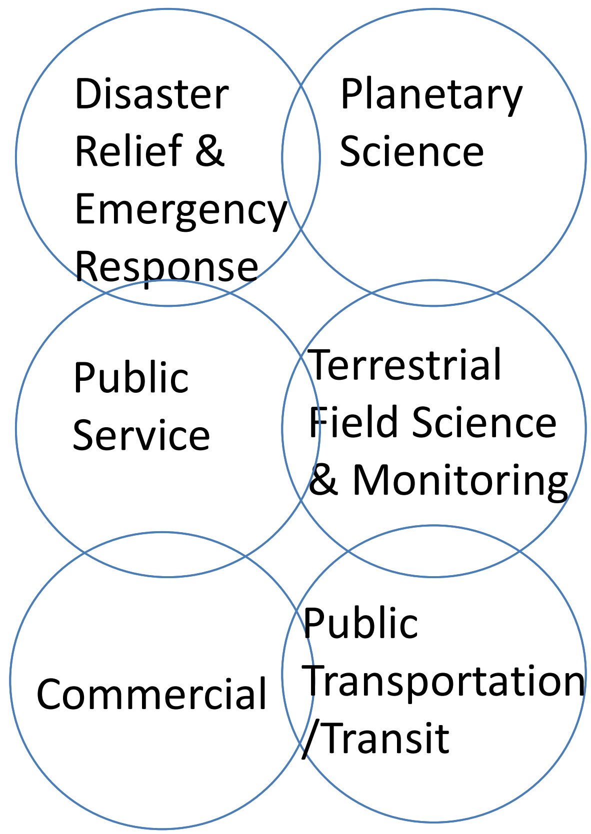
- Application Domain
- Technological Capability
- Transportation "spectrum"

Application

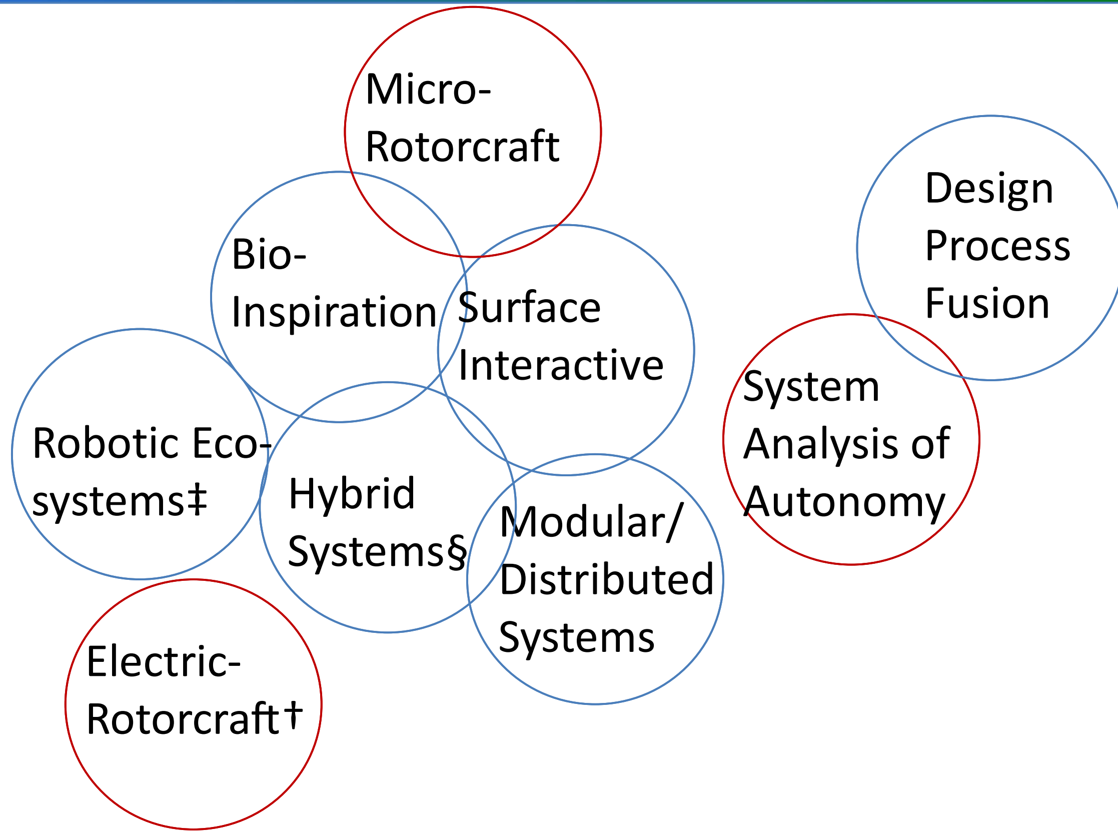
Technological Capability

What is "Transported"

Application Domain Perspective



Technological Capability Perspective

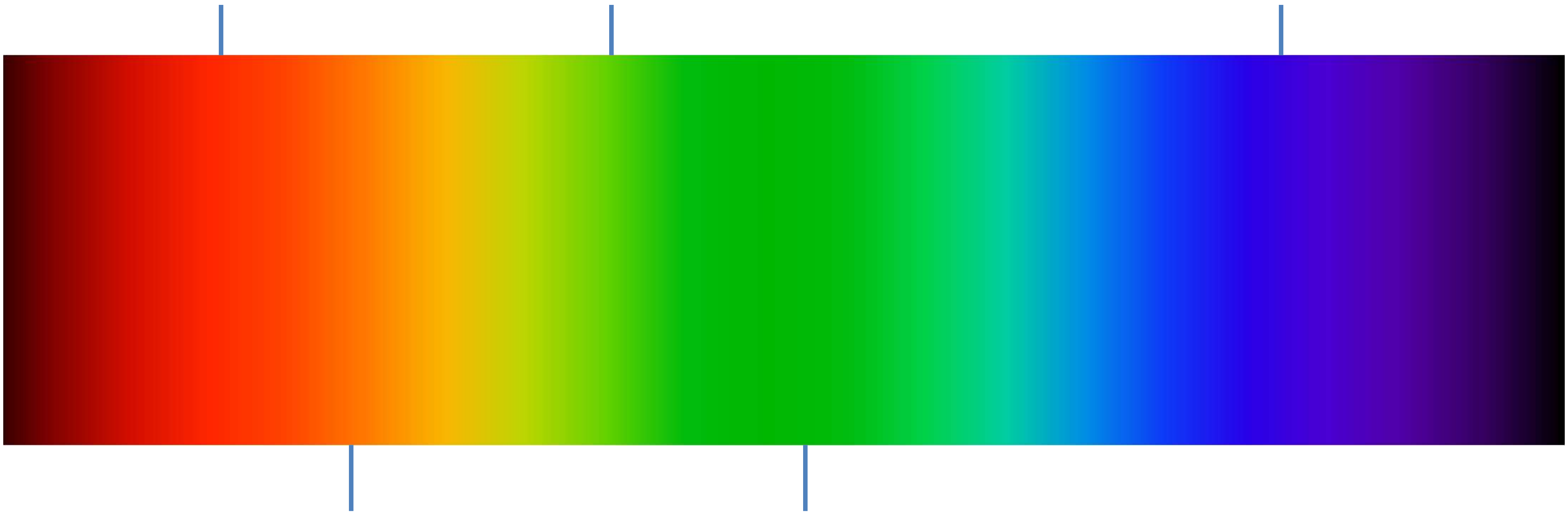


†Encompasses not only electric propulsion but active rotor and flow control via electro-mechanical actuators

‡Networks of homogeneous and heterogeneous agents for not just a single mission but a complete system life cycle

§Heterogeneous combinations of configurations, capabilities, or modalities

Transportation “Spectrum” Perspective



Smart Rotorcraft Field Assistants

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Redefining what a Robotic Explorer Might Be

As well as redefining what a helicopter is … what a robot is …

Terrestrial Field Science and Monitoring

Surface Interactive (& Robotic Ecosystem)

Sample Acquisition

Smart Rotorcraft Filed Assistants

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Terrestrial Field Science and Monitoring

Surface Interactive (& Robotic Ecosystem)

Sample Acquisition

- Aerial imaging is a necessary, but not necessarily sufficient, requirement for SRFA, or other aerial explorers
- Robotic field assistants must provide a utility to the scientist that maximizes scientific return on investment, while preserving personal safety and minimizing resources required
- Could provide a long term, persistent scientific presence in the field if combined with automated stations

SRFA & Arctic (Devon Island) Science

- Characterization of permafrost depth and density
- Snow melt, and/or hydrodynamic, survey
- Assess ongoing foreign flora contamination of Devon Island site
- Expand upon geology/mineralogy surveys of coastline
- Assess glacier morphology
- Continue assessment of biology of impact craters
- Improve understanding of gully formation in valleys
- Understanding biochemical and paleo-bacteriological implications of hydrothermal vents
- Examine the ground/atmospheric heat transfer mechanisms to understand local climatology during seasonal changes
- Polar bear sentry

SRFA Operational Scenarios

Access to Elevated, or Otherwise, Hazardous Terrain

Characterize Site to Provide Context for Specimen Collecting

Scouting or Expanding Data Gathering Capability

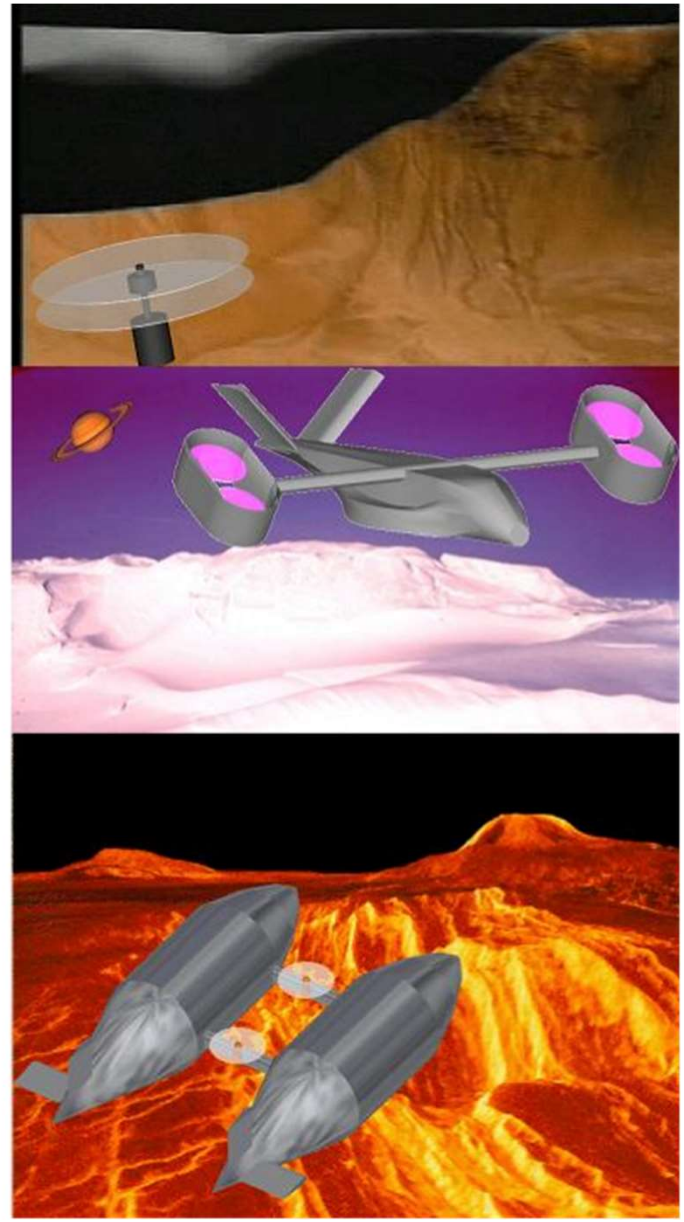
Planetary Science

- Mars, Titan, and Venus planetary science missions could all potentially benefit from using vertical lift aerial vehicles
- A small community of researchers are pursuing this emerging field

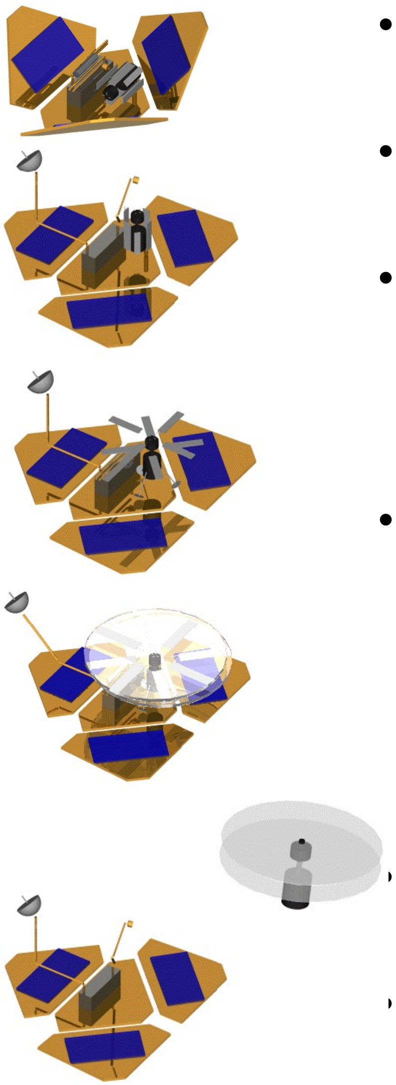
Planetary Science

Surface Interactive & Robotic Ecosystem

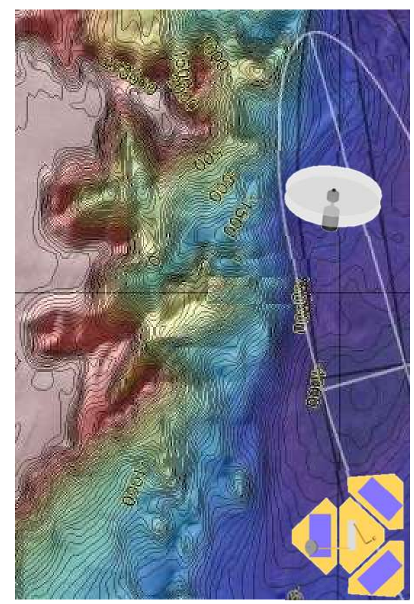
Information & Samples



Mars Rotorcraft



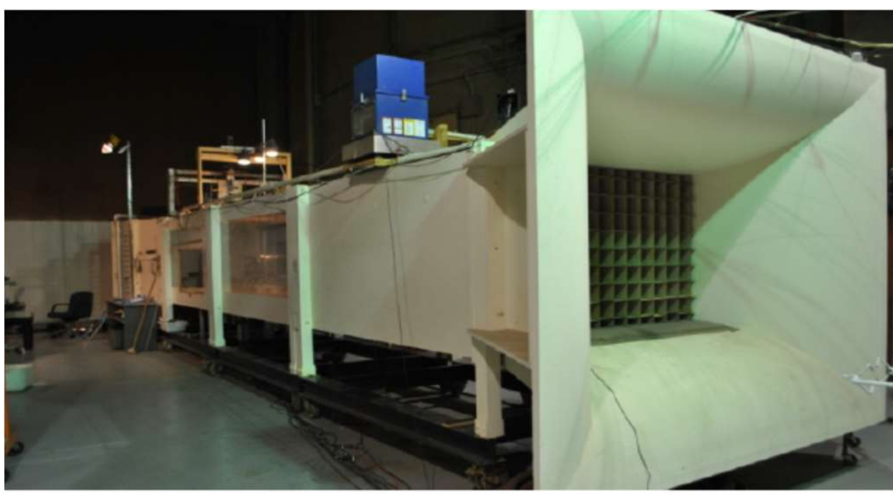
- Large rotors/lifting-surfaces
- Ultra-lightweight structures
- Unique combination of low Reynolds number, compressible aerodynamics for airfoils
- New types of propulsion required: all solar-electric with batteries, fuel cells or Akkerman hydrazine engine, or in-situ-derived bi-propellents
- Unique stability and control challenges
- High level of vehicle autonomy

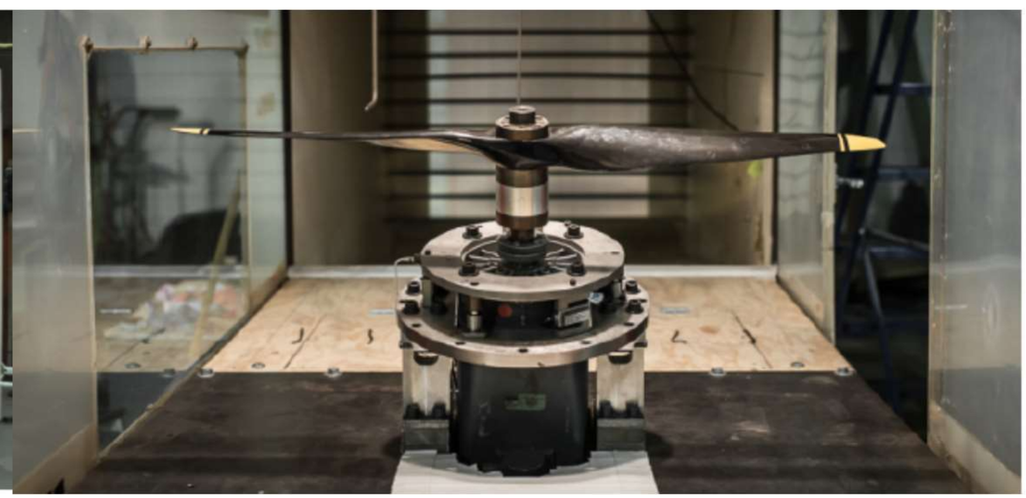


Mars Rotor Hover Testing

NASA Ames:

- First reported rotor hover test at Mars-like densities
- First rotor forward-flight wind tunnel test at Mars-like densities

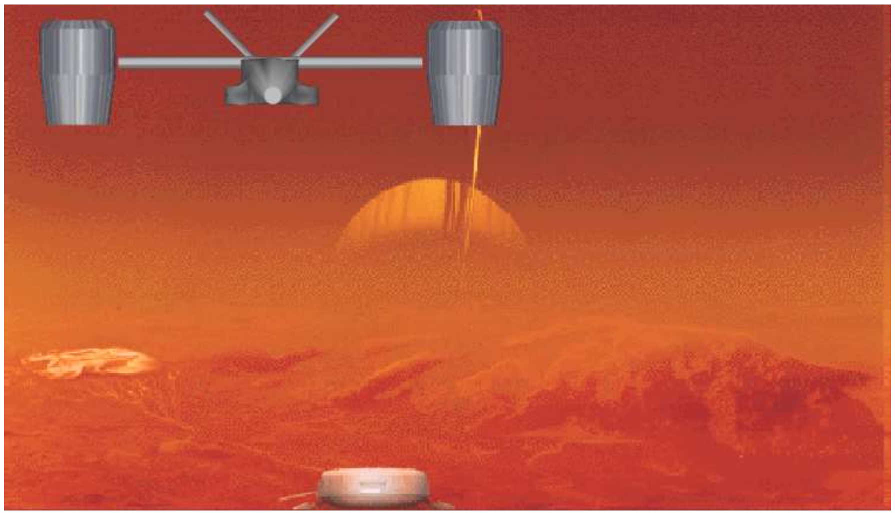




Robotic Hovercraft to explore Titan (a moon of Saturn)

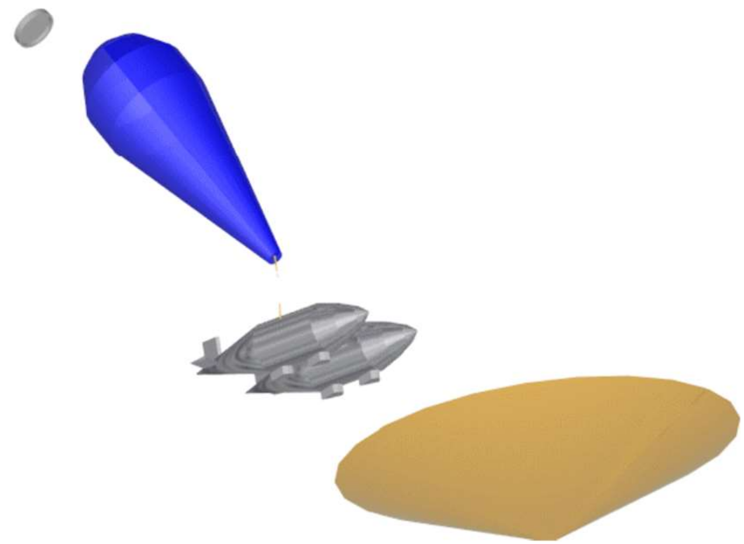
Lipin, A.B., "Robotic Hovercraft for Surface Mobility on Titan A Moon of Saturn," AIAA 2008-7890

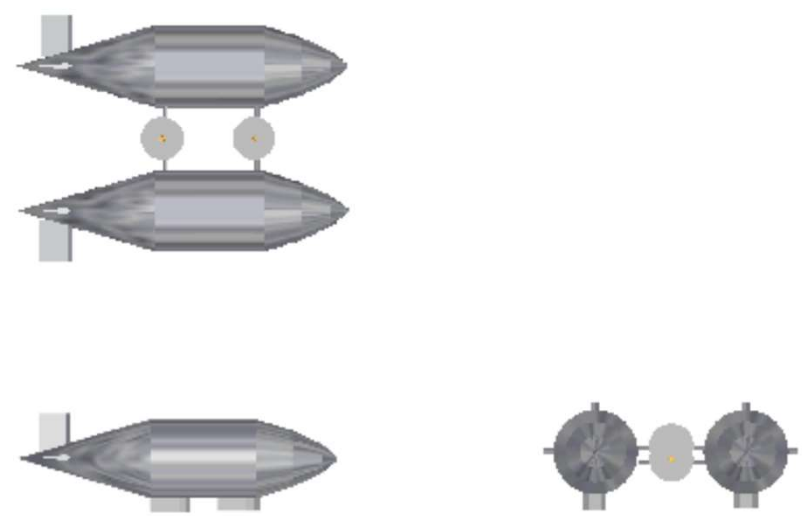
Titan Ducted-Fan VTOL



Venus Hybrid Airships

- Assessing atmospheric & geophysical differences between ‘twin planets’ (Earth and Venus) essential to understand evolution of planetary bodies
- Venus represents greatest challenge for vehicle development
- Low altitude aerial and/or surface exploration in an extremely hostile environment





That was then and this is now…

- Ingenuity Mars Helicopter
- Titan Dragonfly
- And more, hopefully, to come…

Image credit: NASA JPL

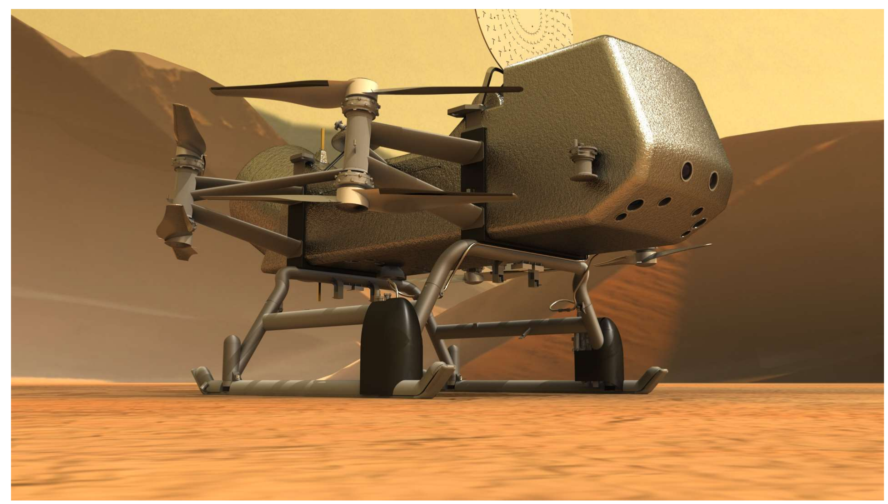


Image credit: Johns Hopkins APL

Examples of Robotic Ecosystems

- It's not just the aircraft or the single mission, the complete vehicle life-cycle needs to be considered; e.g. (semi-) automated bases
- Sentinel fire-spotter
- Aerial Surveyor earthquake damage assessment
- 'Hopper' metropolitan aerial transportation systems

Sentinel Fire-Spotter

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Public Service

Robotic Ecosystem & Surface Interactive

Information Gatherer & Service Provider

Aerial Surveyor

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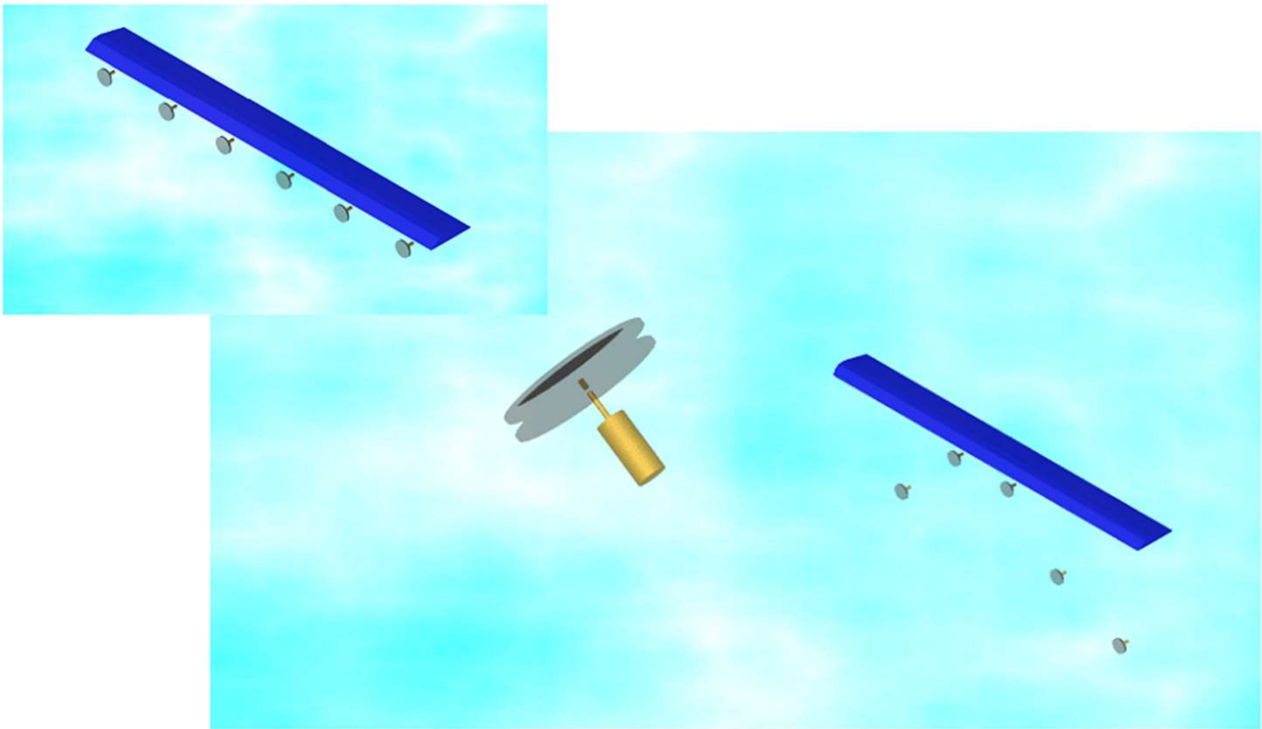
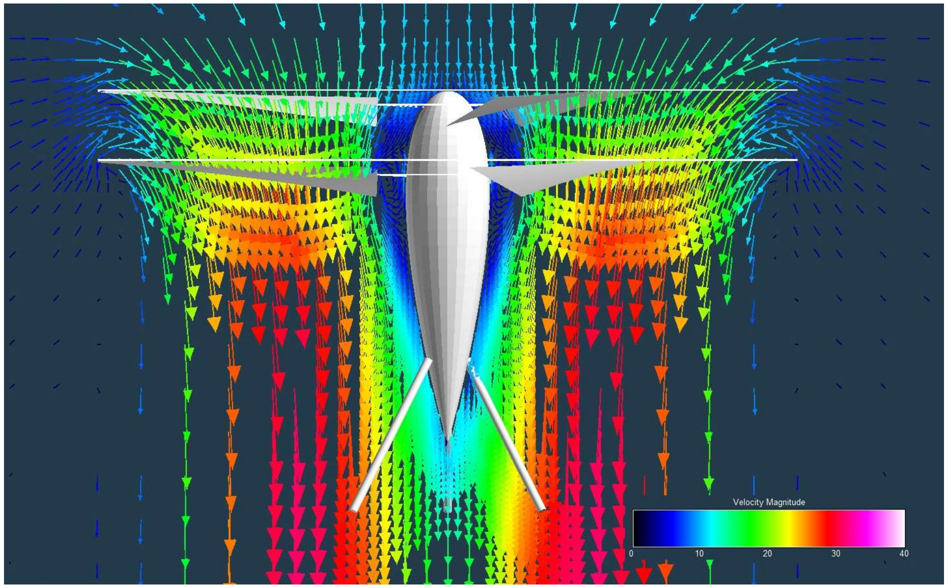


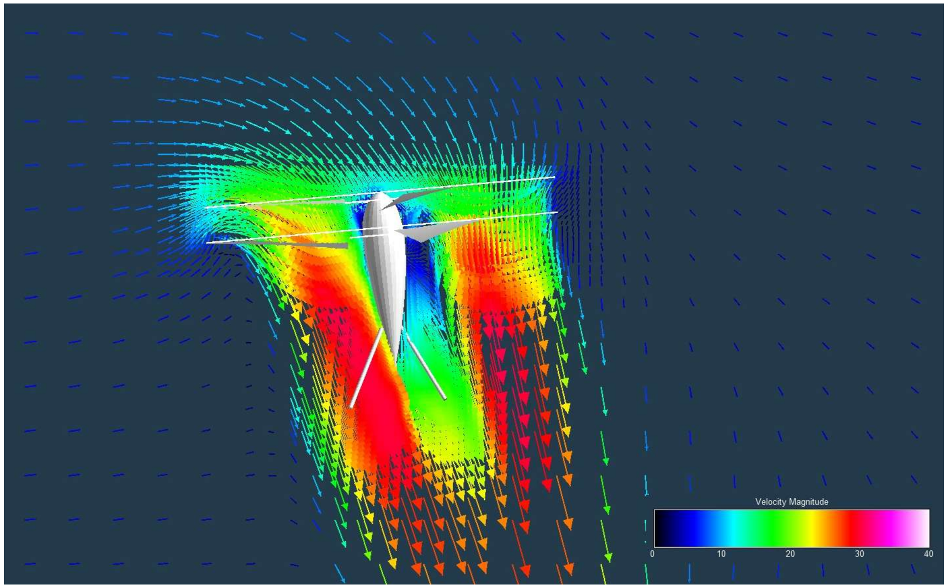
Disaster Relief

Hybrid System

Information Gatherer

Aerial Surveyor



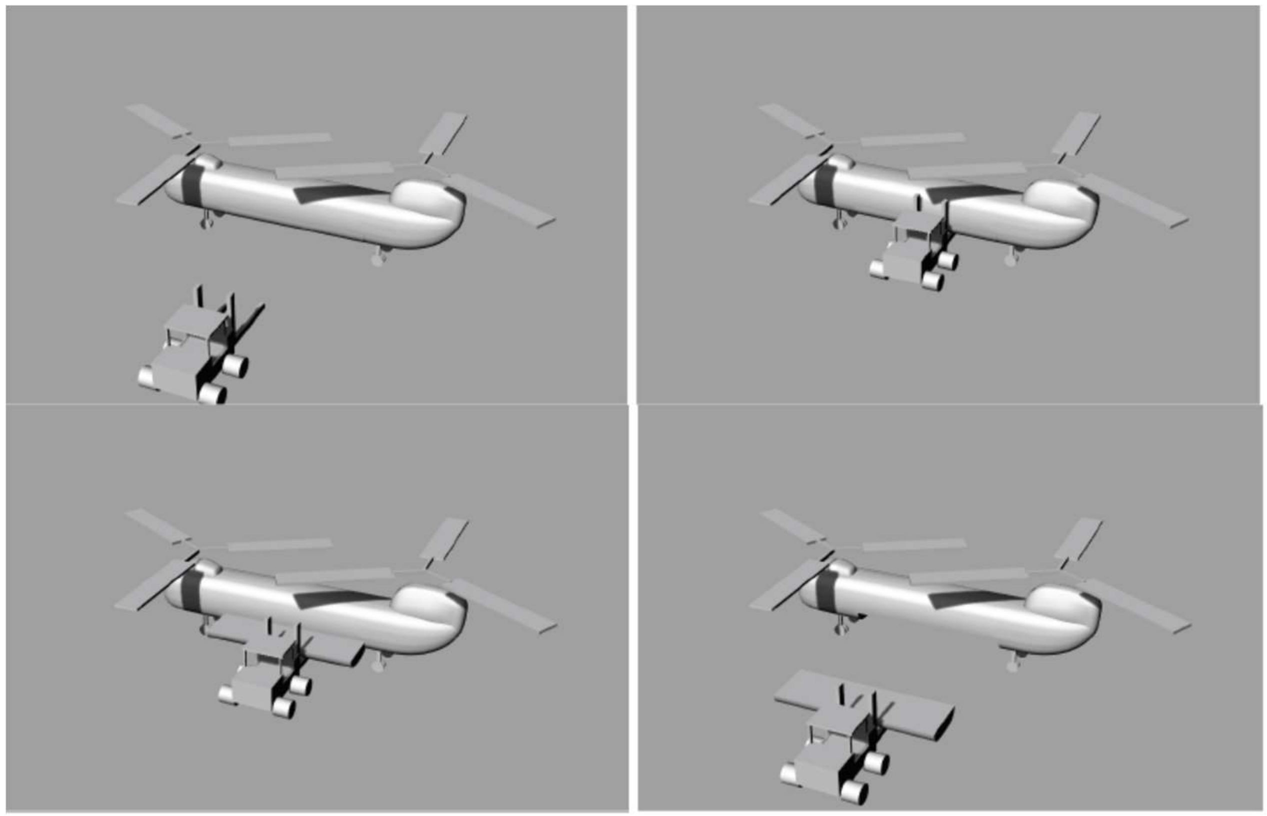


Young, L.A., Aiken, E.W., and Briggs, G.A., "Smart Rotorcraft Field Assistants for Terrestrial and Planetary Science," 2004 IEEE Aerospace Conference, Big Sky, MT, March 2004.

DeBusk, W.M., "Daughtership Release Flight Dynamics of the Aerial Surveyor Hybrid Autonomous Aircraft," AHS Specialist's Conference on Aeromechanics, San Francisco, CA, Jan. 23-25, 2008.

‘Hopper’ Metro-Regional Aerial Transportation System

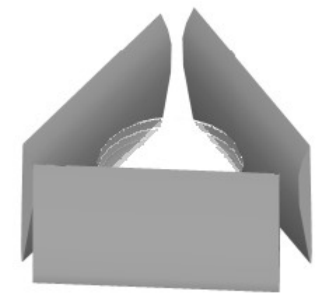
- Autonomous vehicles ultimately will be required
- Scheduled service over with well-defined vertiport networks
- Vertiports will require a large number of autonomous support systems

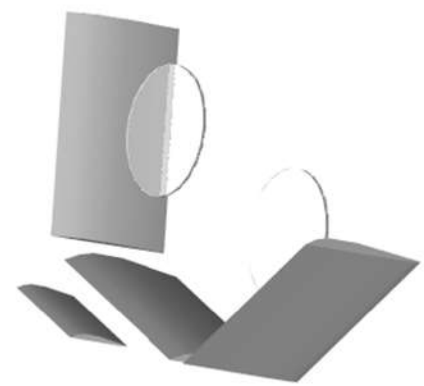


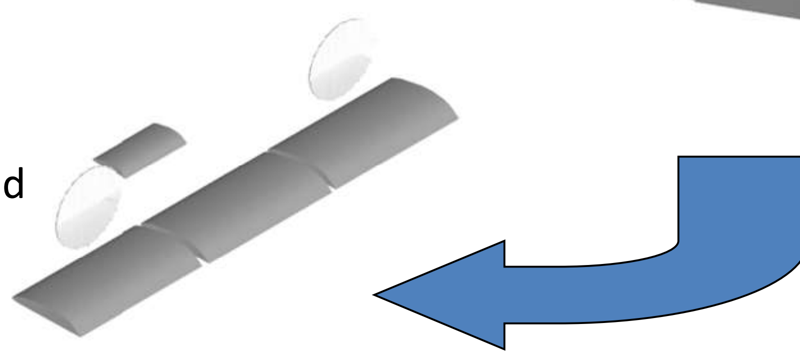
Alonso, J.J., Arneson, H.M., Melton, J.E., Vegh, J.M., Walker, C., and Young, L.A., “System-of-Systems Considerations in the Notional Development of a Metropolitan Aerial Transportation System: Implications as to the Identification of Enabling Technologies and Reference Designs for Extreme Short Haul VTOL Vehicles with Electric Propulsion,” NASA TM 2017-218356, September 2017.

Micro-rotorcraft and Aerobots as a Ubiquitous Part of Society

- Micro- and mini-scale aerial robots can also acquire design attributes embodying configuration change, as in transformation, or morphing, and an almost organic capacity of movement
- There would seem to be an optimum niche of vehicle scale wherein the transformative forces for change, or movement, are small enough to be matched by actuators/effectors sufficiently large in size to apply those forces
- Further it is in this world of the small where new types of vehicle configurations such as hybrid air-cushion/helicopter vehicles and biomimetic rotary-wing vehicles that flitter, skim, skip, or jump, or transform themselves might be feasible
- The end product will be ‘aerobots,’ that will seamlessly integrate themselves in human society and perform many critical societal need functions

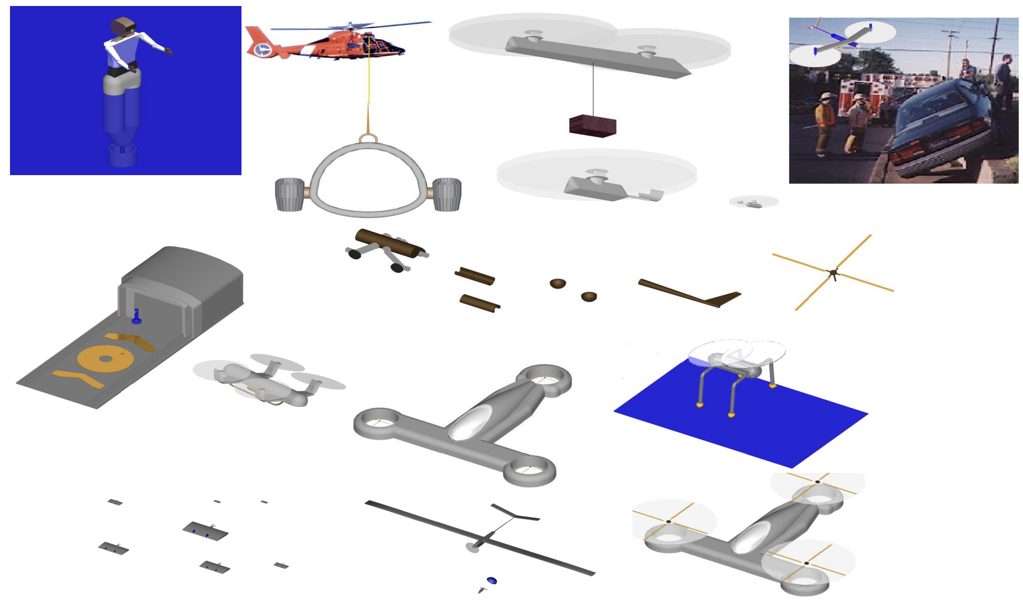






Disaster Relief and Emergency Response

- This continues to be rotorcraft's finest domain/application
- Synthesis of robotics and intelligent system technologies with rotorcraft will be a powerful enabler



Young, L.A., "Small Autonomous Air/Sea System Concepts for Coast Guard Missions," USCG Maritime Domain Awareness Requirements, Capabilities, and Technology (MDA RCT) Forum, Santa Clara, CA, May 2, 2005.

Young, L.A., "Future Roles for Autonomous Vertical Lift in Disaster Relief and Emergency Response," Heli-Japan 2006: AHS International Meeting on Advanced Rotorcraft Technology and Life Saving Activities, Nagoya, Japan, November 15-17, 2006.

Young, L.A., "Enhanced Rescue Lift Capability," 63rd Annual Forum of the AHS, International, Virginia Beach, VA, May 1-3, 2007.

Young, L.A., "Rotorcraft and Enabling Robotic Rescue," Heli-Japan 2010: AHS International Meeting on Advanced Rotorcraft Technology and Safety Operations, Ohmiya, Japan, Nov. 1-3, 2010.

DeBusk, W.M., "Unmanned Aerial Vehicle Systems for Disaster Relief: Tornado Alley," AIAA 2010-3506.

SPRITES

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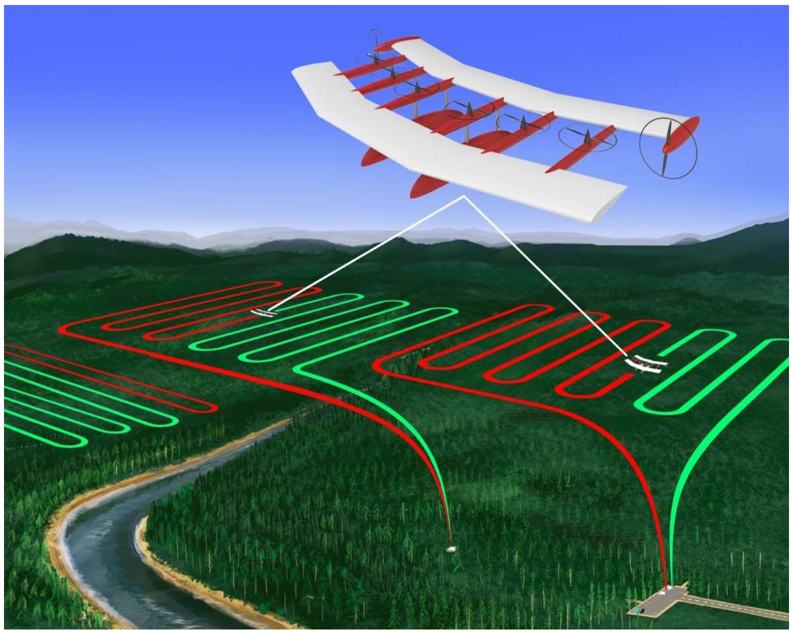
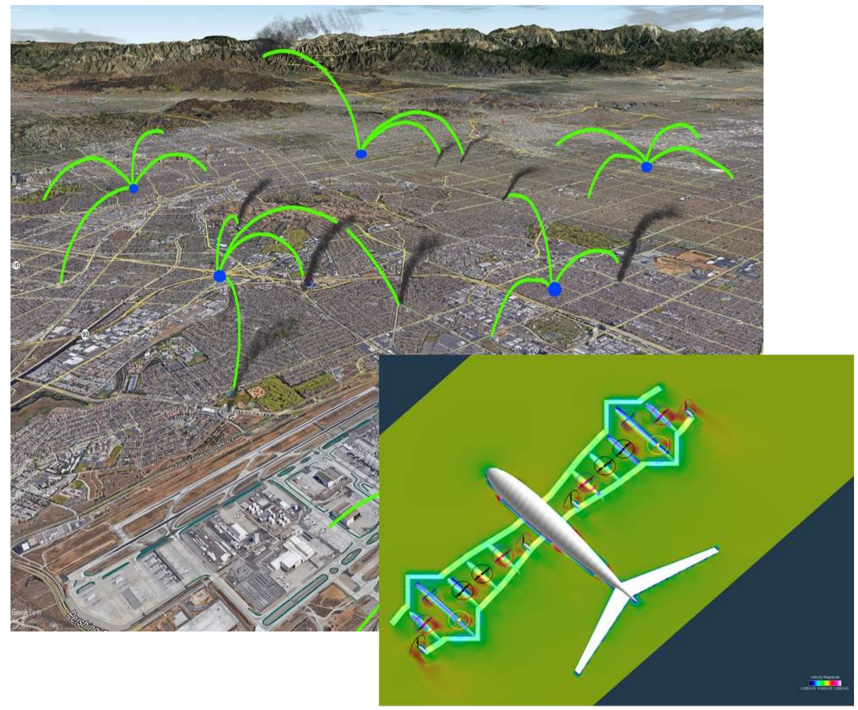
Search and Rescue



Small Aid Package Delivery Mission



Young, L.A., “Smart Precise Rotorcraft InTerconnected Emergency Services (SPRITES),” AIAA Science and Technology Forum and Exposition (SciTech 2018), Kissimmee, Florida, January 8-12, 2018.

Multi-Modal Delivery Drones

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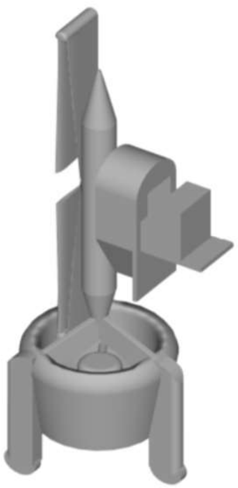
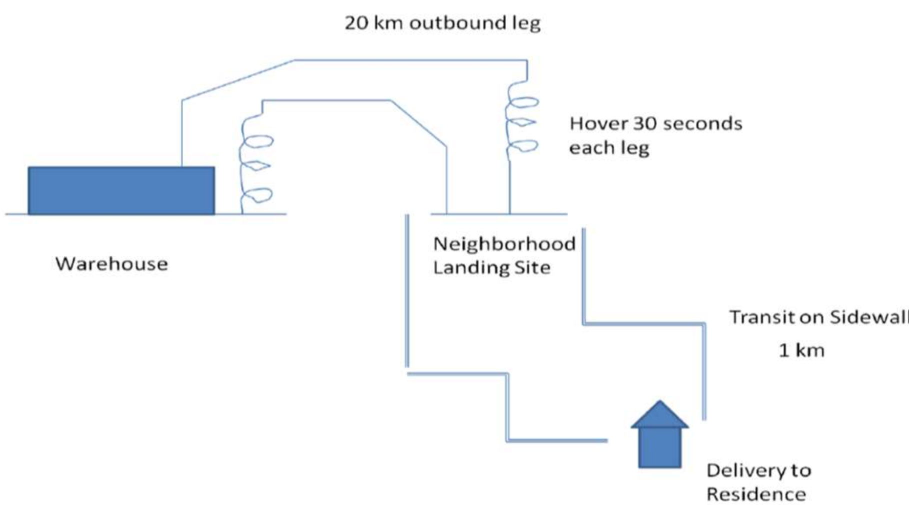
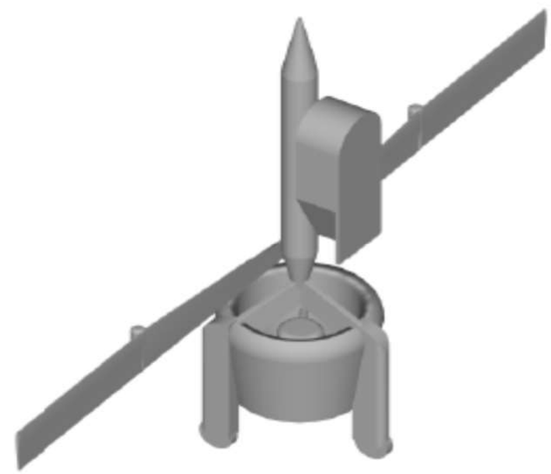


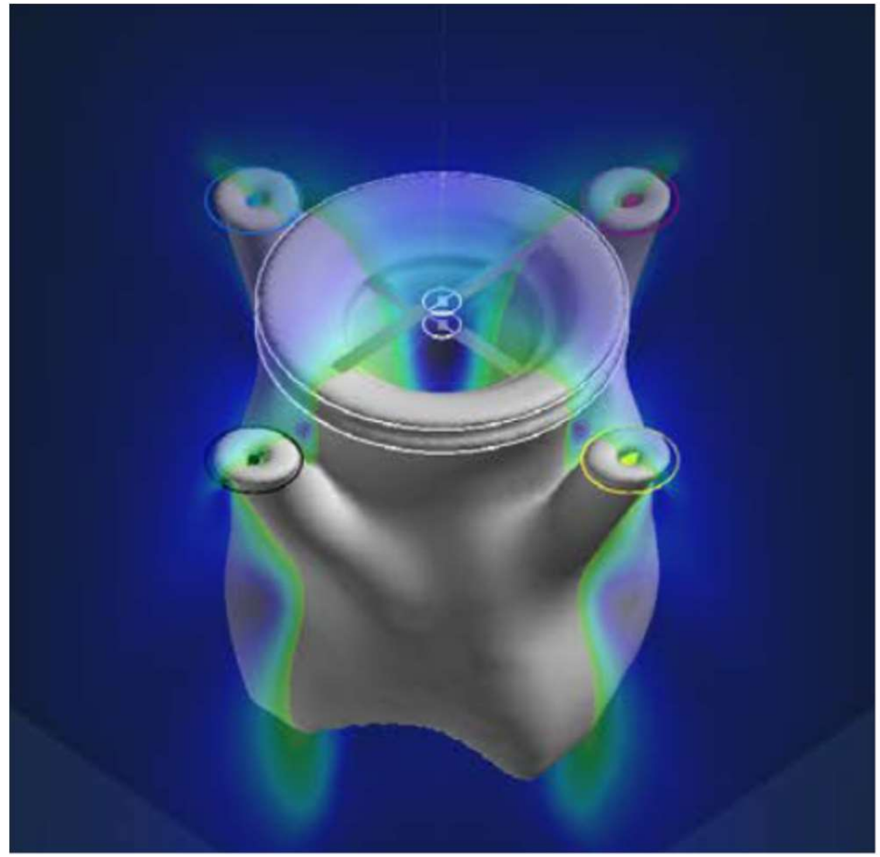




Young, L.A., "A Multi-Modality Mobility Concept for a Small Package Delivery UAV," 7th AHS Technical Meeting on VTOL Unmanned Aircraft Systems, Mesa, AZ, January 24-26, 2017.

Heterogenous, Distributed, and Modular Multi-Rotor Configurations

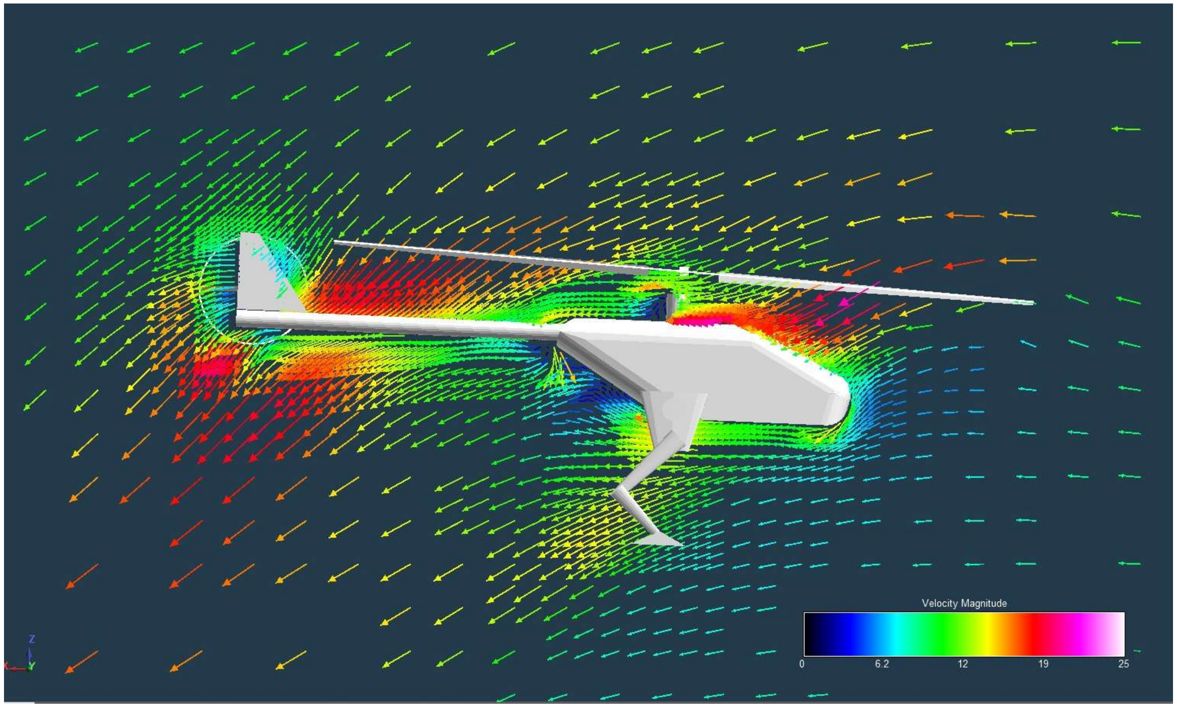
- Two- and three-dimensional arrays or matrices of heterogeneous rotors can be tailored for multiple objectives
- This represents a new field of rotorcraft design



Young, L.A., "Conceptual Design Aspects of Three General Sub-Classes of Multi-Rotor Configurations: Distributed, Modular, and Heterogeneous," Sixth AHS International Specialists Meeting on Unmanned Rotorcraft Systems, Scottsdale, AZ, January 20-22, 2015.

Hybrid Mobility

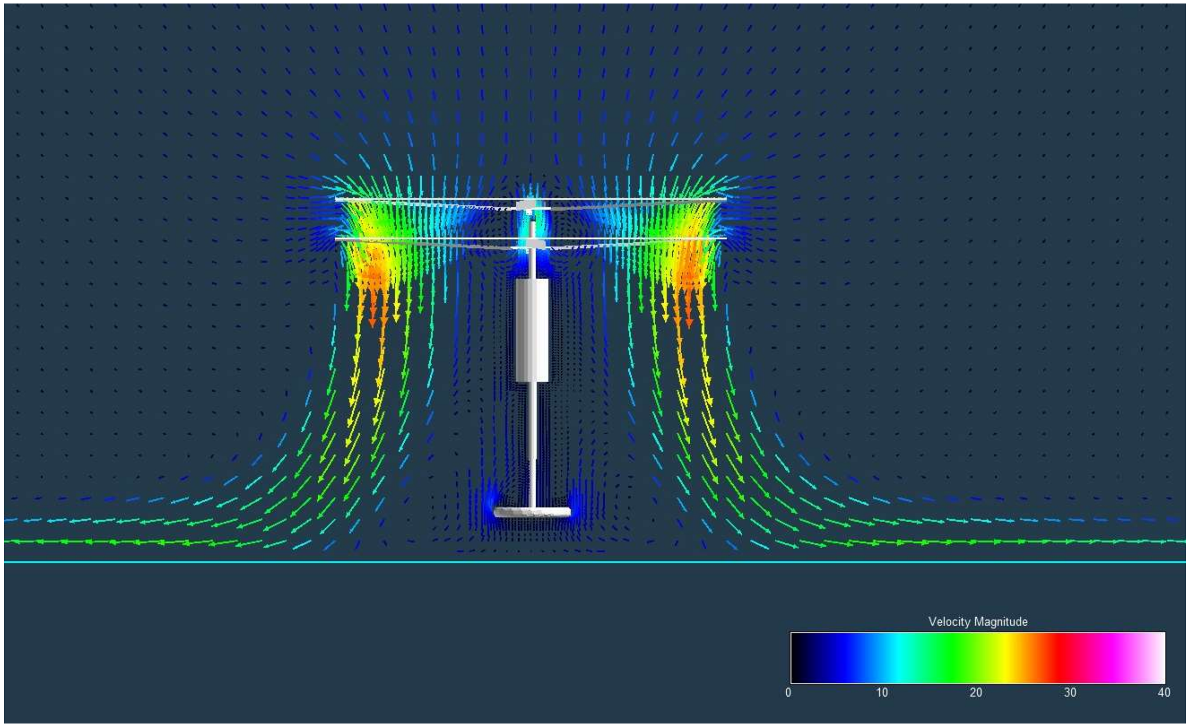
- Walker
- Different modalities for mobility
- Bioinspiration and robotics: “mech-life”



Hybrid Mobility

- Pogo
- Hopping or jumping combined with rotary-wing flight
- Search for improved efficiency
- Partial-power or autorotative state could be tailored in flight trajectory for additional mobility efficiencies

Baba, M. and Young, L.A., "Study of a Hybrid Locomotion Vehicle Using Skipping and Flying for Planetary Exploration," International Academy of Astronautics (IAA) Space Exploration Conference, IAA-SEC2014-WA1483, Washington, DC, January 9, 2014.



Hybrid Mobility Concepts

Surface Interactive
Grippers/Arms
Scoops
Drills/Augers
Tethers
Probe/Ballista Launchers
Specimen Sampling
Penetrators
Micro Rovers
Deployable/Distributed Sensors

Ground Mobility
Wheels
Tracks
Skis/Sled
Skimobile
Hovercraft
Legs
Pogo/Spring-like Hops
Rolling of Sphere/Ellipsoidal Body
Rollers/skids
Telescoping Platforms

Aerial Mobility
Quadrotor or Multi-Rotor "Drones"
Conventional Helicopter Types
Hovercraft
"Flying Trucks/Jeep" Configurations
Tiltrotors/Tiltwings (two or more rotors)
Ducted-Fan/Tilt-Nacelle Aircraft
Balloons and Airships
Fixed-Wing Aircraft
Tailsitters
Compound (wings, lifting-rotors, & propellers) Rotorcraft
Hoppers (cold gas thrusters)
Rotary-wing Hoppers
Ornithopters/Flapping-Wing Aircraft

Liquid Surface Mobility
Floatation Devices (static or drifting)
Power boats
Submersibles (bathosphere, powered, or glider)
Sailboats
Airboats
Paddles
Paddle Wheels
Flippers
Water-walking legs

Universal Flying Machines

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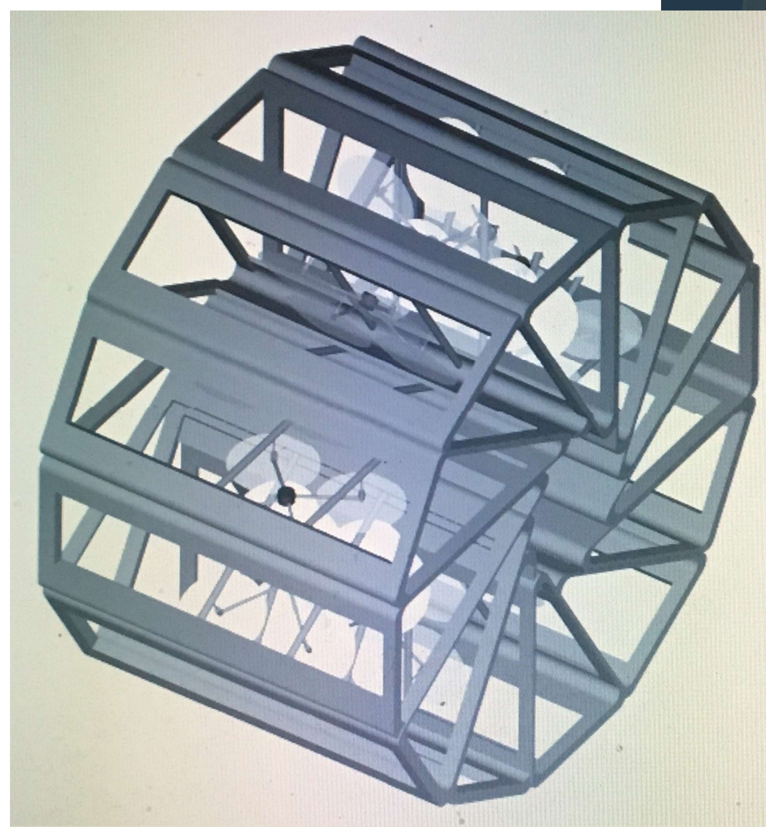
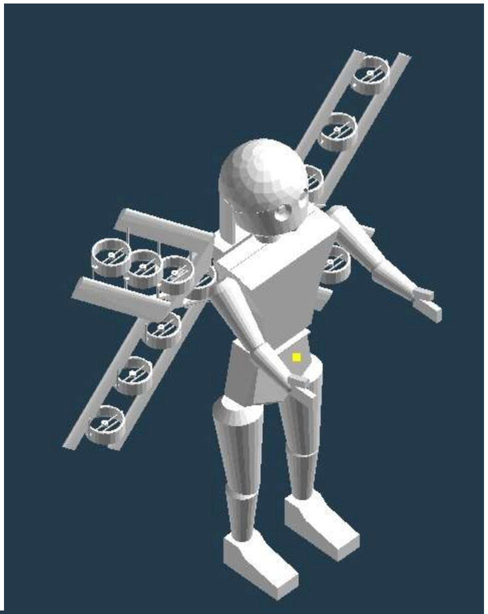
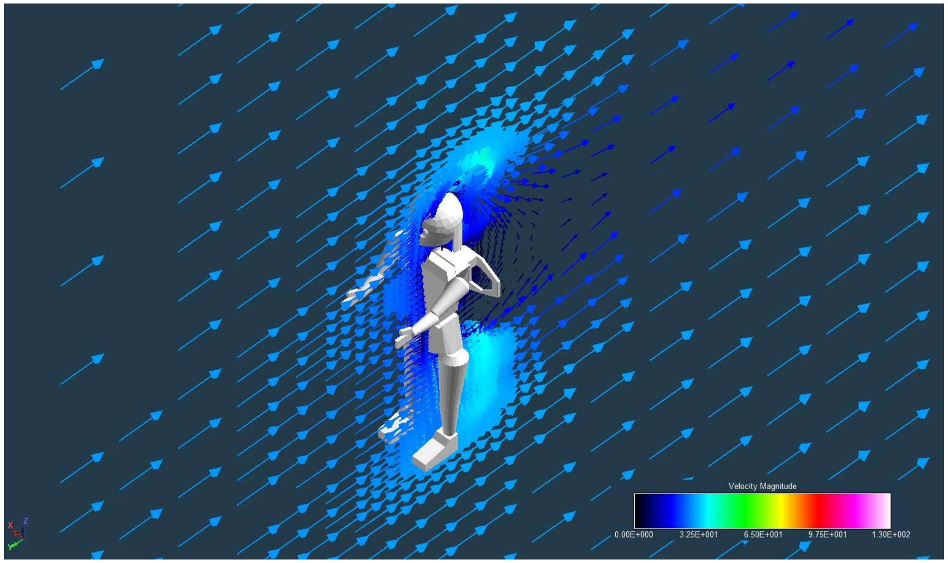
- To go beyond ‘swarms’ and consider instead ‘elements’ and ‘collectives’
- To design stationary or mobile collective assemblies of multi-rotor flying elements that can separate and reform upon need
- Collective robotic movement effected by rotor(s) thrust rather than linear actuators, servos, and electric motors

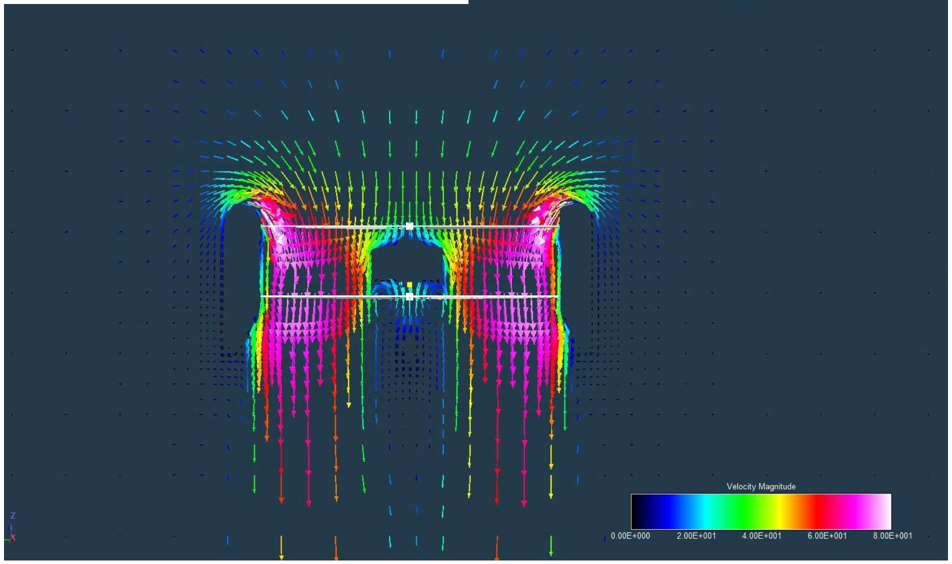


AETHER

- Need for 'rescue robots' for disaster relief and emergency response
- Tight integration of humanoid robot and "personal" vertical lift advancements







Systems Analysis and Autonomy

- Statement of the problem:

- First, what is the optimum level of vehicle autonomy and intelligence required for a particular UAV mission/application?

  – assure acceptable levels of success and risk
  – keep development and implementation costs to a minimum

- Second, what are the specific attributes of an autonomous system implementation (technology portfolio) essential for a given mission/application?

Expansive Levels of Autonomy

Level	Description
10	Legacy/Legate
9	Human Explorer Assistant
8	Integrated, Optimal Autonomy & Design
7	Robotic Ecosystem -- Participant
6	Robotic Symbiosis -- Leader/Co-Equal
5	Robotic Symbiosis -- Subordinate
4	Opportunistic Self-Modifiable Goals/Lines of Investigation
3	Search, Inquiry, Decision through "Discovery"
2	Changeable (though still scripted) Mission
1	Execute Pre-Planned Missions

Young, L.A., "Feasibility of Turing-Style Tests for Autonomous Aerial Vehicle 'Intelligence'," AHS International Specialists' Meeting on Unmanned Rotorcraft, Chandler, AZ, January 23-25, 2007.

Young, L.A., Yetter, J.A., and Guynn, M.D., "System Analysis Applied to Autonomy: Application to High-Altitude Long-Endurance Remotely Operated Aircraft," AIAA Infotech@Aerospace Conference, Arlington, VA, September 2005.

Young, L.A., Pisanich, G., and Ippolito, C., "Aerial Explorers," 43rd AIAA Aerospace Sciences Meeting, Reno, NV, January 10-13, 2005.

Autonomy, Intelligence & Elegance

- ***Autonomy*** metric identifies how much human intervention is required for the aerial vehicle to do its mission
- ***Intelligence*** metrics identify how successfully the aerial vehicle can perform its tasks given varying degrees of operational complexity and uncertainty
- ***Elegance*** metrics identify how computationally efficient and robust the aerial vehicle can perform its tasks

Design Process Fusion

- There is strong interest in robotics community for research into aerial robotics
- There are opportunities for rotorcraft research community to become engaged in robotics research
- This will require adjustments between both technical cultures
- Further, design processes will need to undergo some level of fusion/synthesis to arrive at good designs; e.g. there are no conventional aerospace weight equations for robotics systems
- Nonetheless, there is a significant set of societal problems that could at least be partially addressed by development of aerial robots

Concluding Remarks

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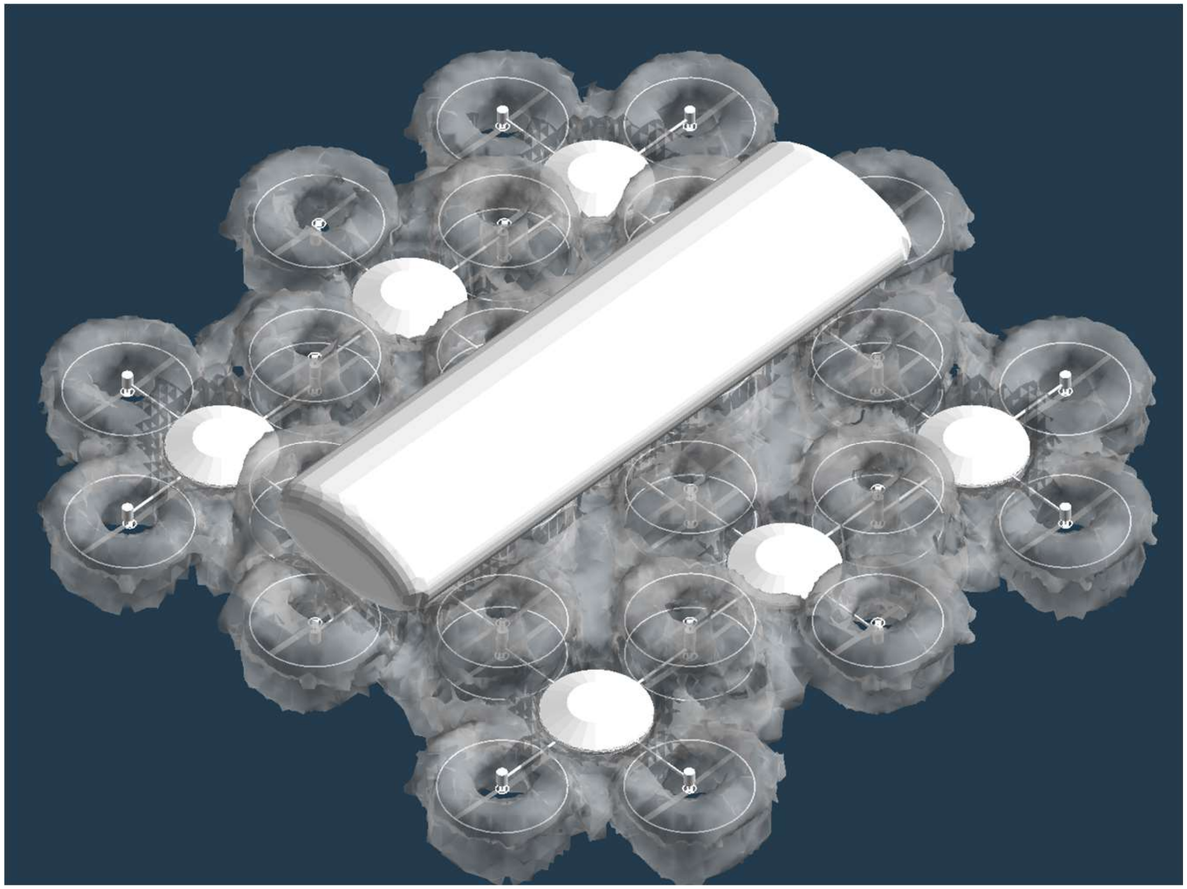
- There is much promise but also much concern as to this ongoing fusion of intelligent systems, robotics, and aerial vehicle design: we have to be wise as much as we are smart

- If we succeed, the outcome will be new knowledge, new services, new capabilities that we could only previously imagine



Questions?
And, by Necessity, Incomplete Answers

Or, alternatively, refer to

http://rotorcraft.arc.nasa.gov